Consortium GARR

THE ITALIAN EDUCATION & RESEARCH NETWORK

Considering the Next Generation of GARR Network

WHITE PAPER

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Disclaimer

Executive summary

The Research and Education (R&E) users' requirements are evolving rapidly. GARR has clear indication of the constant increase in traffic, storage and computing demands for R&E. Technologies in information and communication (ICT) at the same time continue to deliver unprecedented capabilities.

The White Paper has the objective to inform the GARR community at large about the challenge and to start a process to address it successfully, considering it an opportunity. The advances in ICT and the innovation created mostly from large content provider, offer a great chance to match up to the new requirements and innovate in services for R&E.

This White Paper is a first step to define, together with the GARR community, a strategy to rethink the infrastructure and services. The position outlined is that the next generation of the infrastructure needs to be substantially different from what has been engineered in the past.

This document presents a vision for the principles of the new GARR network infrastructure based on collected users' requirements and on technology trends. The new infrastructure will be a tight coupling of software and hardware and no longer just a network according to its traditional definition.

Many challenges are foreseen, among which the development of new skills and competences is a priority within GARR organisation as well as in its community.

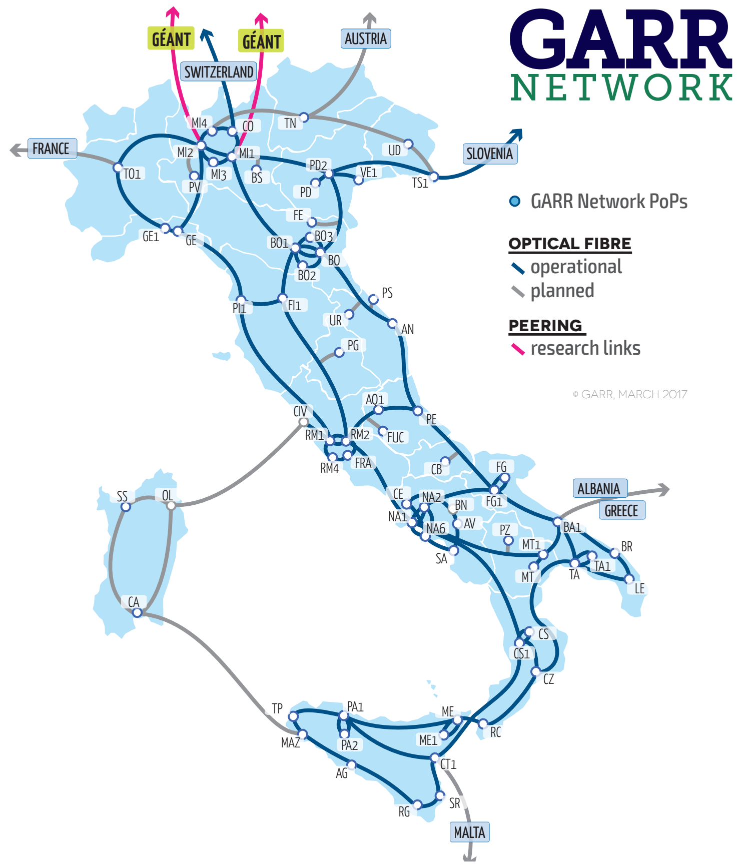
1. Introduction

The networking landscape is rapidly changing both in technology and in the end users' approach. The development in ICT technologies continues to keep its very high pace. Their advances imply a leap in the potential of research and education, providing computation, memory and transmission capabilities that are orders of magnitude larger every few years. While such capabilities open new paths to research previously unavailable, their widespread adoption creates various challenges, significantly on energy consumption, management, security and privacy.

The end users' approach to networking is evolving towards taking networking for granted, as a commodity, invisible tool, which connects the end user to the requested resources, anywhere at any time. The single user is more and more the leading actor in digital communication and now expects that all services will be easily accessible using a simple and clear interface. Considering services, the end user, often nomadic and off-premises, has become as relevant as large physical sites.

Consortium GARR provides very high speed connectivity and services on top of the network to the Italian R&E community. The services are delivered through a 15000 kilometres of fibre infrastructure directly owned and managed. More details on GARR community, network and services are reported in Appendix.

Figure 1
GARR Network
optical backbone



This White Paper argues that a substantial change in networking architectures is needed for the development of the new generation research and education networks. The multi-dimensional scaling challenges cannot be faced by simply scaling the existing architecture, due to the resulting high cost and management complexity. The new architecture will have to leverage the easy and inexpensive availability of powerful merchant silicon to standardise the hardware base and to extensively use software to automate, to make agile and to rapidly create customised services, adapting the ICT.

This White Paper is organised as follows: Section 2 presents an overview of the most significant users' requirements for the network as well as the requirements coming from the management and operations of GARR itself. Section 3 summarises the technological key trends for the evolution in networking. Section 4 presents a vision of the new architecture, as a contribution to a process which has to involve the whole GARR Community and the International R&E networks. The final section presents challenges and outlines the next steps.

In the Annex, two sections are dedicated to the detailed presentation of GARR community and of GARR network, in terms of size, use, services and architecture.

The evolution of the network has to be rooted in a comprehensive analysis of users' requirements. The need for more capacity is still a major drive, however users are requesting new services in many areas, notably security, trust and identity, computing and distributed collaboration.

A preliminary overview of users' requirements[1] is presented, followed by the requirements for the network itself, as emerged during a first set of internal consultations.

[1] See the initial survey presented at the GARR Workshop 2017, Rome, 4-6 April 2017

2. The evolving requirement scenario

2.1 User requirements

A precise set of technical requirements for the network has been identified by consulting GARR community. The main element gathered from users' feedback is a demand for an increase in support and services, which is expected to be the key to make the best use of capacity and physical resources. The requirements are often expressed by both end users and site administrators and refer more to the availability and capability to access services, than to the access to raw capacity.

It's worth noting also the growing requirement to access digital infrastructure services, like computing and storage, and also application-level services as large-data transfer services, research portals and e-learning resources.

The following list elaborates on the identified requirements.

- **Capacity, delay and delay variation.** Ever since the beginning of research networking, the key users' requirement was to access high network capacity between universities and research institutions and to general Internet. The expected capacity varies amongst user communities, being very high in selected sites, usually research facilities, which need to be connected to alike facilities in Italy or abroad through the pan-European academic backbone GÉANT. The absolute value of 'high capacity' has changed by at least three orders of magnitude during the two decades of GARR lifetime. Nowadays the figure is 100G at the high end of the scale, about 10G for universities and research institutions and around 1Gb/s for all others institutions, with the exception of schools that have an initial connection at 100Mb/s. During the last 10 years, the shift from leased circuits to dark fibres allowed GARR to respond to the increasing capacity demand and it is the key element to bridge the digital divide in the community. Fibres can easily accommodate upgrade requests, while they cater for overprovisioned backbone circuits and abundant user access capacities. The bulk of core research traffic consists of large data samples that are moved to be processed or stored continuously and often within a short time-frame. Such traffic exhibits a pattern in time of a constant high traffic volume base-line, with superimposed high peaks. Such traffic is sensitive mostly to capacity. However, the total traffic is composed also by a much larger number of flows which are smaller in transfer sizes. These are generated more and more by applications which are highly interactive, real-time and often involving voice or video. The trend implies further requirements to ensure that the network ensures minimal or no packet loss, delay variation and minimizes the packs travel delay.

- Ubiquitous availability. The presence of GARR network is a prerequisite to provide each member of GARR community the same opportunities independently the geographical location of users' sites. The requirement is best matched by using optical fibre, which does not restrict capacity and framing type. Figure 1 shows the current dark fibre footprint of the GARR backbone. Most of access links are already implemented through dark fibres and the plan is to have a complete users' access through the fibre medium.
- Service availability. Users require a complete reliability and continuity for connectivity and all the services delivered through the network.
- Security, privacy. Security has significantly raised its priority in the last few years. Cyber-attacks, like a Denial of Service, are more and more frequent, complex and even if they do not compromise systems or information may severely impact the targeted service or institution. The demand for tools to detect vulnerabilities and mitigate security threats has increased. The ability to provide robust security services for incidents detection and mitigation, involving all network access points, is the key towards a global protection. Tightly coupled to security, the request for privacy protection is also high and may bring to ubiquitous encryption, starting from end-to-end traffic, similarly to the decision of many content providers.
- Traffic separation, Virtualization. An increasing demand for Virtual Private Networks (VPN) is coming from a subset of users in the GARR community. VPN services are requested among Italian sites and also to connect researchers in multiple countries.
- Access to expertise and specific ICT skills. The perceived lack of specific ICT skills is a growing concern for researchers, educators and for the support groups providing the resources to the end users. It is not simply caused by lack of time to acquire new notions on how to use new equipment. It derives from the introduction of key paradigm shifts in hardware and software, which are changing the way to use technology and require a complete restructuring of knowledge. The shifts are taking place very fast worldwide making even harder to define strategies and investments in human competences and skills.

2.2 GARR internal requirements

The requirements in a nutshell derive from the need to anticipate and to comply with growing complexity, size and users' requirements.

GARR network continues to evolve, becoming larger and is required to maintain agility and scalability at similar or lower total cost. GARR network has also grown in complexity in the past years and we expect these trends to continue at faster pace in the future. The complexity comes not just from scaling in size (i.e. the number of nodes, circuits, services) but also from the need to effectively assist a growing users' community.

A consequence is the requirement for an improvement of the network management model currently adopted by GARR. The direction is to reduce the substantial human intervention in the day by day operations and the control activities. Although some aspects are already automated (e.g. monitoring), most activities rely often on human intervention: new activations or termination of services, updates of network, fault and performance management, accounting. This entails that, the more the complexity, the more the effort from specialised personnel increases, posing constraints to growth and to its pace.

The ever-increasing interest in joining GARR network (particularly from schools and university separate branches) together with the raise in advanced services delivered on top of the physical connectivity places further weight on the requirement for efficient growth.

The direct management of both network and services is an essential element for GARR, which implements and operates a multi-vendor and multi-layer infrastructure as a single domain. A basic requirement to achieve this goal efficiently, is to rely on to open standard protocols and interfaces in each network building block, from devices (proprietary or white-boxes) to control planes (APIs, north/south bound interfaces).

A requirement arising from the Network Operation Centre is the necessity to unify all the possible management heterogeneous tools in a customisable dashboard. The dashboard should be able to provide an at-a-glance overview of each layer both in term of monitoring and provisioning, with modularity and extensibility, integrating automation facilities embracing different layers and technologies. Finer-grained and extended control, together with monitoring of the equipment in all network layers are also enablers to match the new users' requirements.

Such an integrated system is expected to enable GARR to deploy agile network services and favour the rapid development of much-needed automation facilities. Such environment should be flexible enough to allow network engineers and developers to mutually swap their roles, during service implementation and delivery phases.

A continuous knowledge training activity, of both GARR personnel and technical focal points of the connected institutions and end users is a core requirement to enable the evolution. As network models shift/move from vendor lock-in to a more open approach (as summarised in the next section) it is essential to facilitate the development of new tools, procedures and skills within GARR, which should leverage the open approach to all components of the infrastructure. Such approach becomes mandatory in an integrated environment where interaction between a large number of contributors, equipment and software, and even between different network layers and organisations, is crucial.

3. Technological trends

The extremely successful developments in the silicon industry are at the bottom of most, if not all innovations in ICT. Hardware enhancements constantly improve miniaturization, facilitate a ubiquitous and inexpensive distribution of digital elements, increase performance and, above all, make a reality the implementation in software of functions previously requiring dedicated hardware.

The impact of merchant silicon and software on networking is changing the way networks are engineered and managed and how network services are designed, developed and delivered.

The following briefly describes the ongoing evolution in two focal areas: optical transport and upper layers softwarization.

Optical technology is a main actor in network evolution, delivering ever increasing bandwidth interconnections, dynamically and in a pervasive and effective way. Innovation and development in optical modulation and spectrum management place dense wave division multiplexing (DWDM) transport platforms as a crucial area to enable enhanced services.

Recent innovations in optical networks move forward the traditional static environment of DWDM and transport layers, unlocking an optical platform as a fully flexible resource, able to be managed and orchestrated according to services and user policies.

Industry state of the art pushes towards disaggregation, i.e. separating a system into components, to achieve an agile optical network deployment, capable of flexible network customisation and allowing vendor diversity. This trend is favouring a multivendor open environment instead of the current vendor locked-in solutions. The following list identifies current optical network evolution trends:

- Optical programmability and flexibility: deployment of coherent transceivers, flex-grid and multi-degree Reconfigurable Optical Add and Drop Multiplexers.
- Network Element Disaggregation: starting from software and hardware decoupling, the trend of network function disaggregation is enabling an open optical platform approach, giving the opportunity to achieve an effective tailoring of network design.
- Multi-Layer integration: only apparently in contrast with the disaggregation trend, much of the data packet forwarding capabilities can be integrated within the transport platform, avoiding expensive duplication of functionalities between the two layers.
- Multi-Layer orchestration: achieving an effective multi-layer orchestration of a programmable optical layer and a packet layer allows to define fine-grained, on-demand optical layer resources, matching the overlay network requirements and creates service/application awareness of the network.

The appearance of new paradigms relying on the use of software is evident in many areas, including networking. In software, there is a clear trend towards the development of open source code, based on large communities that include also vendors.

In networking, and distributed systems, these trends are very evident and are accelerating the rate of change.

An end-to-end orchestration is the core function of such complex systems and can be engineered based on the following pillars. All are technologies rapidly moving to production-quality components:

- Automation and Infrastructure-as-a-Code: users' networks are defined as comprehensive configurations that are implemented in the real infrastructure. Automation is not only a set of tools: it's an innovation process towards the Development-Operation (DevOps) philosophy that can improve overall manageability, responsiveness and agility in delivering future services.
- Software Defined Networking (SDN): clearly separates functions between hardware (e.g. forwarding) and software (e.g. path computation). A controller relies on Open Interface in all network elements to control and configure the network and exposes a northbound interface to application.
- Network Function Virtualization (NFV): separates the function from the hardware, so that it can be virtualized in merchant silicon. The trend considers augmenting traditional PoPs with cloud data centre elements, also referred to as NFVI or edge computing. NFVI PoPs are equipped with virtual infrastructure managers, typically based on OpenStack Layer

3-7 services are obtained by routing the user traffic flows through chains of Virtual and Physical Network Functions on top of the links created inside the NFVI PoPs.

- **Management and Orchestrators (MANO) frameworks:** unify the view and the control of all the elements in the next generation network: NFVI PoPs, SDN and Optical controllers, and also virtual functions. MANOs enable portals to schedule the creation of new services for the end users by automating their life cycle management. Orchestration, SDN and NFV are enablers for delivering overlay networks to the users.

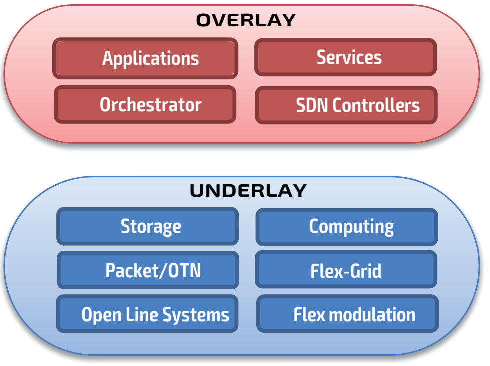
4. Vision for new architecture

The vision has the objective that the network is capable of supporting the identified requirements expressed by research and education community and that can continue to evolve rapidly. In a nutshell, the next generation of GARR network will provide more and more extremely reliable IP communication at Terabit capacities and it will further enhance security, maintain neutrality and be capable of swiftly offering tailored solutions to different users' needs. The network continues to be at the forefront of technology, more agile in accommodating new services and affordable.

The network and its services will specifically focus on serving in a transparent and direct way the end users, who will have an enhanced direct access to services and be able to combine them through the network, regardless of users' location. The network is expected to be more pervasive and to provide more services, but in a transparent and lightweight way. The network will seamlessly be interconnected with similar networks and federate its services nationally and internationally and ensure access and transfer to very large amount of information in a secure, resilient and cost-effective way.

To implement this vision, the architecture maintains, from a high-level point of view, the layered model with two main layers, referred in the following as underlay and overlay. In this model, software and commodity hardware play a fundamental role and automation is key for a sustainable implementation.

Figure 2
The two-layer model



The underlay contains mostly hardware in form of nodes based on merchant silicon, optics and very few, if any, specialised hardware. The overlay is built mostly by software interacting with users, performing high level services and controlling the underlay.

In the underlay, the use of merchant silicon and the use of the convergence of switching and optical layer will allow to achieve several key objectives: Terabit capacity, scalability, modularity of services, standardisation of interfaces, and reduction of OPEX and CAPEX. The use of fibre remains the key asset to realise the vision. Optical transmission will be able to make the best of the available resources, allowing e.g. fine-grain circuits to be dynamically created. It will also permit an easy integration with packet switching to optimise the services for the users.

The underlay will permit the integration of long haul transmission, with regional and metropolitan aggregation, not just at the packet layer with a possible reduction of the number of Points of Presence. As the hardware is standardised, also the functionalities are only limited by software implementation. The use of virtualization and deep programmability will further enhance and widen its range of application.

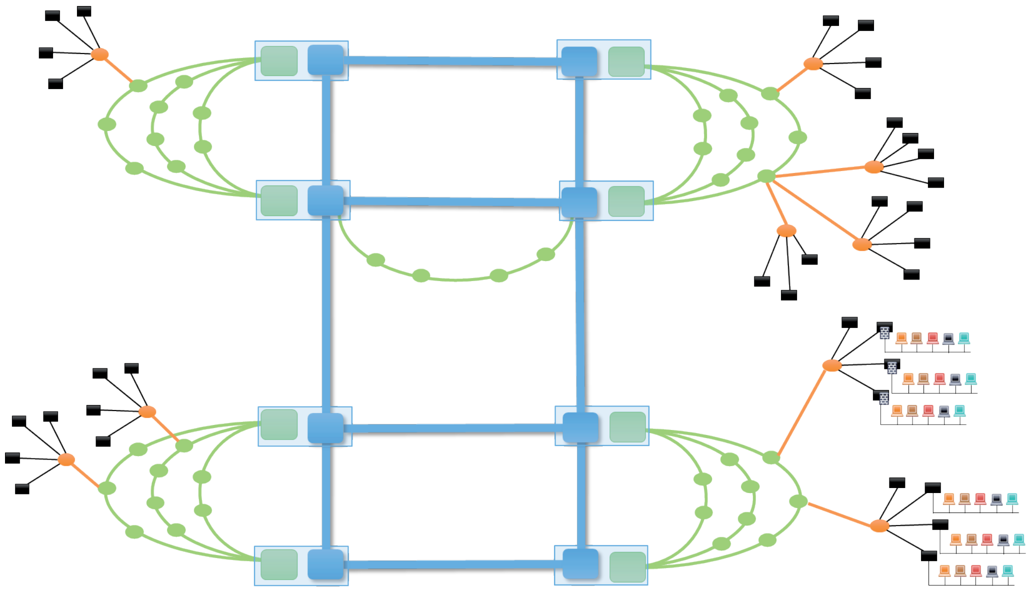


Figure 3
Network vision from the core to the edge

The overlay is devoted to service provisioning. It executes control, management and monitoring. It is based on software, mostly open source and with mandatory open, standard interfaces between its components and towards the underlay (southbound) and towards applications (northbound).
The overlay may exploit virtualization and encapsulation technologies and creates an abstraction of the underlay for services.

The vision described is interoperable with the current network implementation and thus allowing a stepwise implementation, starting from end users and sites benefiting more from the new agile architecture.
The measures to mitigate the various security threats will be from the beginning an essential component of the network and services design.

5. Conclusion and next steps

The combination of users' requirements for new services and greater support and the extremely disruptive technological trends urge a rethinking and reengineering of GARR infrastructure.

The rise and growth of open network equipment and open network environments, together with the wide adoption of open standard interfaces, addresses the need of avoiding to be locked by specific vendor/platforms in the current fast changing technological scenario.

It is foreseeable that networking, service control, provisioning and software development will become much closer each other in an environment where network engineers and developers may, and probably will, join forces.

The evolution process will imply a tight collaboration with the GARR Community to reach a common agreement on how to face and solve challenges and to ensure a substantial evolution and innovation of the competences and skill of all the participants.

The next steps envisage to continue to interact with the users' community to define a common path to innovate the infrastructures, continue to collect and understand user requirements, and leverage the existing experience in the new technologies and start an in–house, rapid prototyping for relevant use cases.

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Appendix

GARR and its community

GARR is the Italian Research and Education network. Its main goal is to provide very high bandwidth connectivity, advanced services and e-Infrastructures support, thus enabling the Italian Research and Academic community to efficiently collaborate worldwide.
GARR network is implemented and operated by Consortium GARR, an independent non-profit organisation since 2003, founded by the following Italian Institutions:

- INFN (National Institute for Nuclear Physics),
- CNR (National Research Council),
- CRUI Foundation, representing the Conference of Italian University Rectors,
- ENEA (Italian National Agency for New Technologies, Energy and Sustainable Economic Development).

Consortium GARR institutional mandate includes the following:

- to implement and operate the national high-speed telecommunication network for University and scientific research, and to interconnect to other NRENs in Europe and worldwide, as well as with the Global Internet;
- to provide the user community with network operation and application services;
- to facilitate cooperation in the field of research through the exploitation of leading-edge e-Infrastructures, both at a national and international level;
- to disseminate advanced knowledge about network infrastructure, and to stimulate the exchange of technical know-how within the user community.

GARR Network connects more than 1.000 sites[2] including research centres, laboratories, observatories and other research facilities, universities, schools, libraries and museums for an estimated end user base of 4 million.

[2] For detailed list of the connected organisations, visit: http://garr.it/it/infrastrutture/rete-nazionale/enti-e-sedi-collegate

In addition to founders' sites, GARR network connects other categories of users, in sectors that are closely related to academia and research. Main communities are:

- **Education:** universities, schools, institutes of higher education, music conservatories and art academies (AFAM).
- **Cultural Heritage Institutions:** e.g. libraries and museums, archives and historical sites.
- **Scientific Research institutions:** ASI (Italian Space Agency), INAF (National Institute for Astrophysics), INGV (National Institute for Geology and Volcanology) or INRIM (National Institute of Metrological Research).
- **Bio-medical Research Institutions:** e.g. IRCCS (Research Hospitals), IZS (Food safety and animal welfare research institutes), EMBL (European Molecular Biology Laboratory), TIGEM (Telethon Institute of Genetics and Medicine), Stazione Zoologica Anton Dohrn or University Hospitals.
- **Technological Research Institutions:** e.g. IIT (Italian Technology Institute) or CETMA (European Research Centre for Technologies, Design and Materials).
- **Agriculture and Agronomics Research Institutions:** e.g. CREA (Council for Agricultural Research and Analysis of Agricultural Economics) and others.
- **Data centres:** e.g. CINECA, CRS4 and CMCC.
- **Public Administration**, when related to Research or Education.
- **Foreign Universities or Institutions** having agreements with the Italian Government.
- **International organisations based in Italy** such as: ESA (European Space Agency), EFSA (European Food Safety Authority) and the JRC (European Commission Joint Research Centre)

Status of GARR network

The countrywide GARR network infrastructure is based on over 15.000 km of backbone and user access optical fibres owned by GARR on the basis of 15-years IRU contracts, or leased from major Italian telecommunication providers. It features overprovisioned connectivity among its users and interconnects with other research networks worldwide and Internet.

The network is directly and completely managed by GARR Network Operations Centre (NOC). In addition to the network services, GARR offers a set of top-of-the-network services related to security, trust and identity management, videoconference and cloud.
The GARR access infrastructure is rapidly evolving towards offering 100 Gigabit per second to the user premises.
The GARR-X optical infrastructure topology, shown in Figure 4, includes two blocks equipped with different Dense Wave Division Multiplexing transport technologies: Huawei (green in the picture) and Infinera (in blue).

The network infrastructure in central and northern Italy is based on the Huawei OptiX platform. The nodes include Reconfigurable Optical Add and Drop Multiplexer (ROADM) modules, supporting up to 80 channels in the C-Band and with a 50 GHz grid and Optical Transport Network (OTN) switching matrices. The channels are mainly 10G with some 40G. Client services are offered at 1G and 10G.

In Southern Italy, the infrastructure is Dispersion-Compensating Module (DCM) free, and coherent technology is used for transmitting the signals. The network is equipped with the Infinera DTN-X platform, capable to transmit multi 500G super-channels in a single fibre. Client services range from 10G to 100G.

Using an in-house developed set-up, based on alien wavelength transport in Infinera and Huawei platforms, GARR is extending the capacity of the backbone circuits at 100G in the national infrastructure (red in Figure 4).

On top of the optical transport, GARR has deployed equipment capable of IP/MPLS for its stability and dependability. IP/MPLS is also used to create the service layer. The entire GARR IP layer is a single geographically-extended domain based on Juniper MX Series. The adoption of the MPLS enables advanced services, like virtual networks to all users regardless of their geographical location. The GARR IP/MPLS logical topology is shown in Figure 5.

Figure 4
The GARR network optical backbone

On the national infrastructure, routers are divided in two main categories: core routers, interconnected at 100G or more (blue in the picture) and aggregation routers (red in the picture). Core routers interconnect directly with the pan-European network GÉANT, Internet eXchange sites, international Content Delivery services (e.g. Google Cache and Akamai

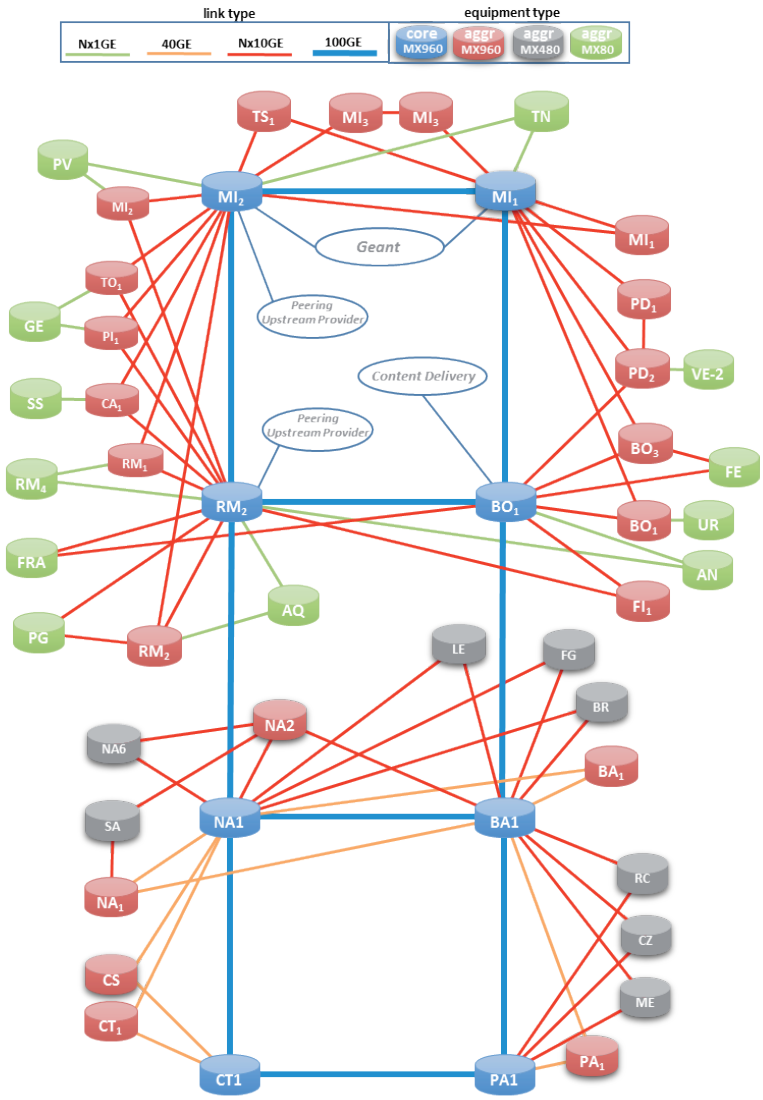


Figure 5
GARR-X IP/MPLS topology

Table 1
GARR-X main peerings

Peering	Bandwidth
GÉANT	200 Gbps
Level3	20 Gbps
Cogent	10 Gbps
MIX	30 Gbps
NAMEX	20 Gbps
TOPIX	10 Gbps
TIX	1 Gbps
VSIX	1 Gbps
Google	20 Gbps
Google cache	10 Gbps
Akamai cache	40 Gbps

Cache), the GARR Mirror and Filesender services, as well as with user sites needing very high access capacities (100 G or multiple 10 G), which include major data centres, laboratories and radio telescopes.

From its beginning GARR network offers IPv4 transport services and since 2005 native IPv6 transport services has been added. Starting from the GARR-X project and the adoption of MPLS in all its nodes, GARR offers an extended set of MPLS-based network services: Virtual Private Network both within GARR MPLS domain and in multi-domain environments including the whole of Europe, and traffic engineering based on RSVP. Independently from MPLS, GARR offers also IP-based QoS and IPv4 and IPv6 multicast services.

Basic GARR services include IPv4 e IPv6 addresses assignment, domains registration under .it and .eu and support to DNS configuration and secondary servers. In addition, services like Security Incidents and Alerts management, Certification Service for personal and server Digital Certificates supply and on-demand network security scanning are available.

GARR also provides other services, including Mirror for software distribution both on IPv4 and IPv6, Filesender for large information sharing, SIP/H323 HD video-conferencing, and support to eduroam ubiquitous wireless connectivity.

Services built on top of the network include personal “sync & share” cloud storage, self-service provisioning of pre-configured Identity Providers to connect to the Italian Identity Federation (IDEM), enhanced multimedia services like web conferencing and low latency advanced audio/video system specifically tuned for Arts and Humanities real-time activities, the Low Latency service[3]. Moreover, the most recent services available for institutions and end users offer big data storage for scientific archives and repositories, Platform as a Service (PaaS) and Infrastructure as a Service (IaaS).

GARR commitment to constantly innovate is reflected in the evolution of its infrastructure and users access links over the years. Two main aspects have driven the change: the optical transport technology evolution and the steady growth of bandwidth demand.

[3] LOw LAtency service https://lola.conts.it

Figure 6 displays the users' access evolution since 2010. The trend shows (blue line in the graph) the growth of the direct connected user sites from about 400 in 2010 to the current 700 and, at the same time, the increase in bandwidth access. The number of circuits having a capacity higher than 1G has constantly increased from very few to one third of the total connected sites. Two main initiatives gave a boost to this change: the implementation of GARR-X (2012) and the GARR-X Progress project (2015). GARR-X implemented a technological evolution which made possible the swift migration from low bandwidth access (up to 100M) to 1G and 10G. With GARR-X Progress, GARR introduced a further technological innovation, offering 40G and 100G access links dedicated to the most demanding users' sites and continued to extend the southern Italy network, significantly reducing the digital divide in the country.

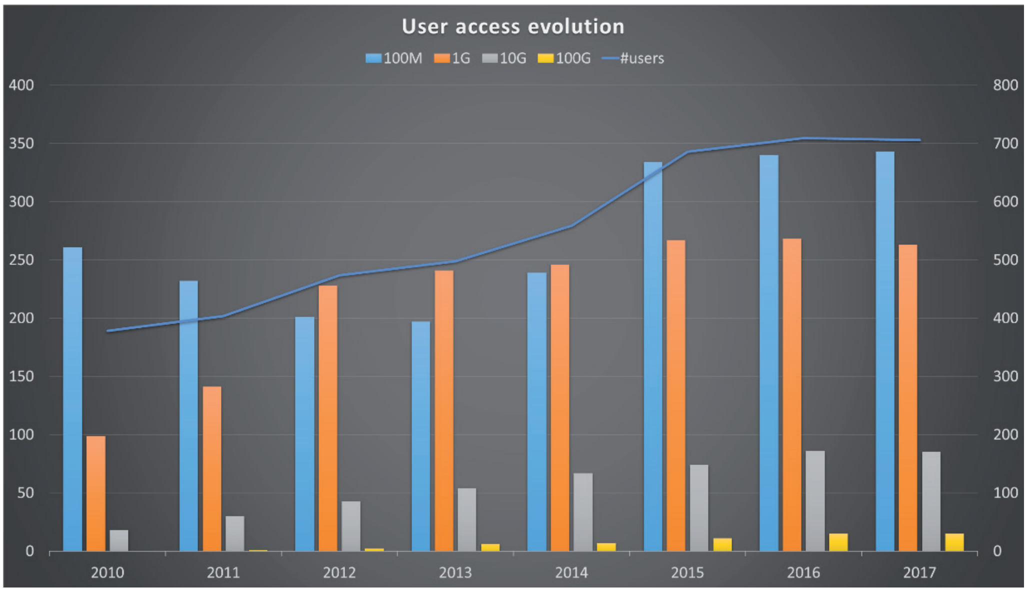
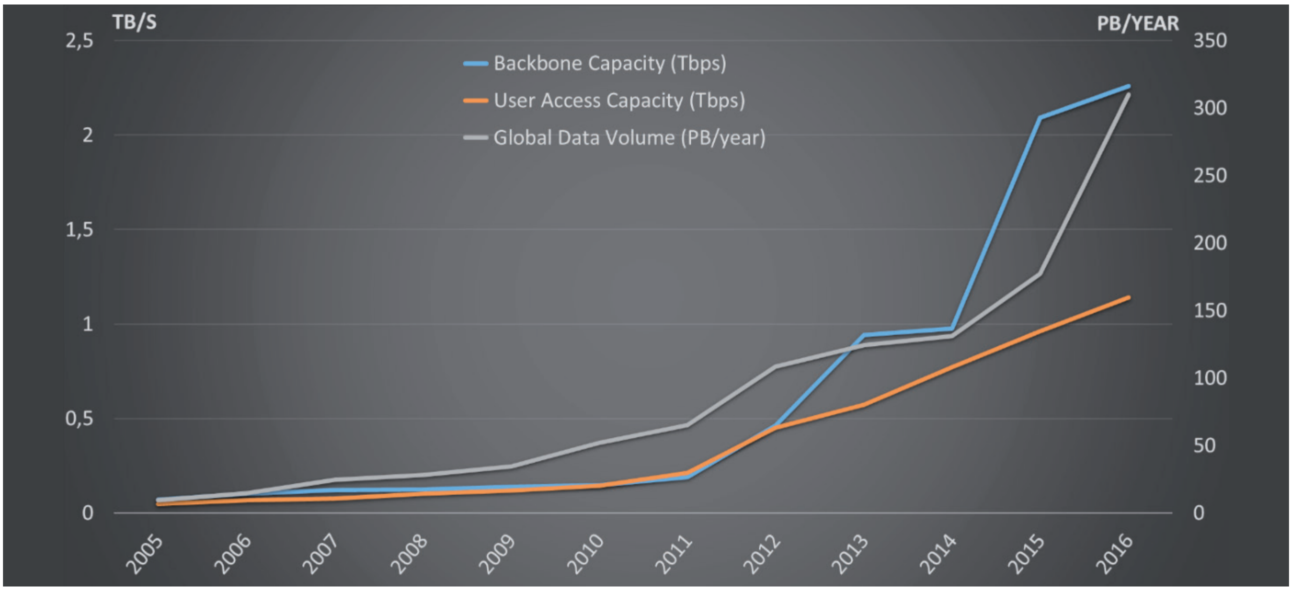


Figure 6
The evolution in link capacity towards users

The improvement to the network allowed the steady increase of the total traffic volume carried from about 50PB in 2010 to 310PB in 2016 (see Figure 7).

As a consequence of the evolution to 100G of the backbone capacity in the national infrastructure and of the increased data production and analysis requirements, GARR forecasts that the exponential growth of traffic volume will continue in the next years.

Figure 7
Total traffic carried by GARR network between 2010 and 2016



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Feedback

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